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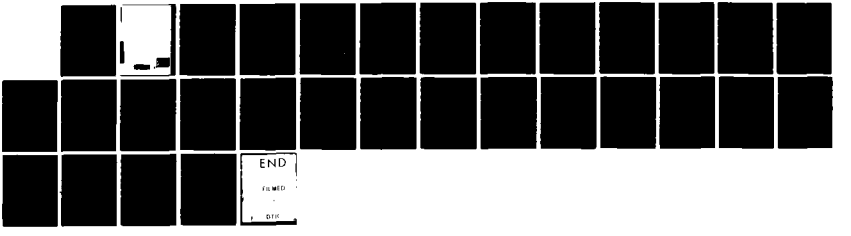

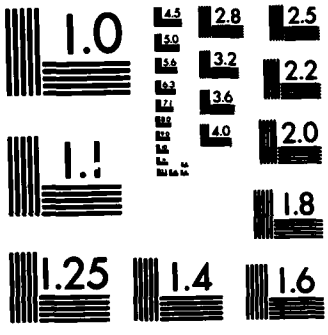

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Flow through bioassays were performed on smolting juvenile coho salmon with sediment from inner areas of Grays Harbor estuary. Previous work has shown that heavy metals have the ability to impair osmoregulatory capacity. Fish were exposed to these sediments for 9 days and then placed in seawater for 24 hours. ~~RESULTS~~ Dredging activities occurring in the inner portion of Grays Harbor are not believed to be causing impairment of migrating smolts.

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THE EFFECTS OF GRAYS HARBOR ESTUARY SEDIMENT ON THE OSMOREGULATORY ABILITY OF COHO SALMON SMOLTS, ONCORHYNCHUS KISUTCH

by David M. Kehoe
U.S. Army Corps of Engineers
August 1982

Many thanks to the U.S. Fish and Wildlife Service and especially to the people at the National Fisheries Research Center at Marrowstone Island, Washington, for their unfailingly excellent technical assistance. Special thanks to Dr. Gary Wedemeyer, who made this all possible.

ABSTRACT

Flow through bioassays were performed on smolting juvenile coho salmon (Oncorhynchus kisutch) with sediment from the inner area of Grays Harbor estuary. Previous work has shown that heavy metals have the ability to impair the osmoregulatory capacity of smolting salmon (shown by increased blood sodium levels), resulting in delayed seawater entry and potentially increasing estuarine predation of the population. The sediments used in this experiment were found to contain heavy metals in both a bulk sediment analysis and an elutriate analysis.

Fish were exposed to these sediments for 9 days and were then placed in seawater for 24 hours ("seawater challenge"). These fish were able to osmoregulate as well as the control group, which was not exposed to sediment prior to a seawater challenge. Similarly, a group of fish allowed to recover in clean freshwater for 5 days following 9 days of contaminant exposure showed no signs of osmoregulatory impairment after seawater challenge. A group allowed 10 days of recovery time after 9 days of contaminant exposure showed signs of osmoregulatory impairment after seawater challenge. This effect was an artifact, possibly due to stress caused by experimental design.

Based on the results of this experiment, the dredging activities occurring in the inner portion of Grays Harbor are not believed to be causing osmoregulatory impairment on juvenile salmon smolts migrating through the area.

THE EFFECTS OF GRAYS HARBOR ESTUARY SEDIMENT ON THE OSMOREGULATORY ABILITY OF COHO SALMON SMOLTS, ONCORHYNCHUS KISUTCH

A major problem faced in salmonid enhancement programs is the low adult return rates of artifically propagated fish (Saunders and Allen, 1976). This often occurs despite the generally higher survival rate of hatchery fish during the hatching and early developmental stages.

One suggested explanation of this problem addresses the ability of the hatchery released fish to undergo a parr/smolt transformation and function as true smolts upon arrival at the seawater/freshwater interface. A number of environmental factors affect the physiological and behavioral processes commonly referred to as smolting. Among these factors is the effect of trace heavy metal exposure during the development of smolts in freshwater. Usually the source of these contaminants is mineral deposit drainages or nonpoint source industrial pollution (Lorz and McPherson, 1976). Partial or complete inactivation for the gill-ATPase system occurs if fish are exposed to 20-30 microgram per liter (ug/l) of copper during the parr/smolt transformation (Lorz and McPherson, 1976). The biological damage is not apparent unless the fish are placed directly into seawater, where hypo-osmoregulatory failures and severe mortalities occur. Synergistic effects with other heavy metals have also been demonstrated (Lorz, et al., 1978). However, if a 5-day freshwater recovery period is allowed before exposure to seawater, survival returns to normal.

In estuaries which have experienced large amounts of heavy metal pollution, the bottom sediments tend to bind the heavy metals from the water column and act as a sink for storage of the contaminants. Dredging activities may resuspend these toxicants in the water column and contact with this material by migrating juveniles may have a deleterious effect on smoltification and early marine survival (Wedemeyer, et al., 1980).

This study examines the effect of Grays Harbor sediments on the hypo-osmoregulatory ability of smolting coho salmon (Oncorhynchus kisutch) through the measurement of blood sodium levels following seawater challenge. The presence of high blood sodium levels is indicatory of osmoregulatory impairment, which has been shown to occur in salmonids exposed to heavy metals during smoltification. These fish were subjected to conditions which were designed to simulate, as closely as possible, the effects on migrating juvenile coho salmon of the periodic high suspended sediment levels created by hopper dredges while dredging in the inner harbor. These bioassays, performed on four groups of coho smolts, attempted to identify the effect of resuspended contaminated sediments on the hypo-osmoregulatory ability of the smolts under these conditions:

o Direct exposure to seawater for 24 hours after exposure to clean freshwater (control).

o Direct exposure to seawater for 24 hours after 9 days of sediment exposure.

o 5-day recovery in freshwater after 9 days of sediment exposure, then exposure to seawater for 24 hours.

o 10-day recovery in freshwater after 9 days of sediment exposure, then exposure to seawater for 24 hours.

METHODOLOGY

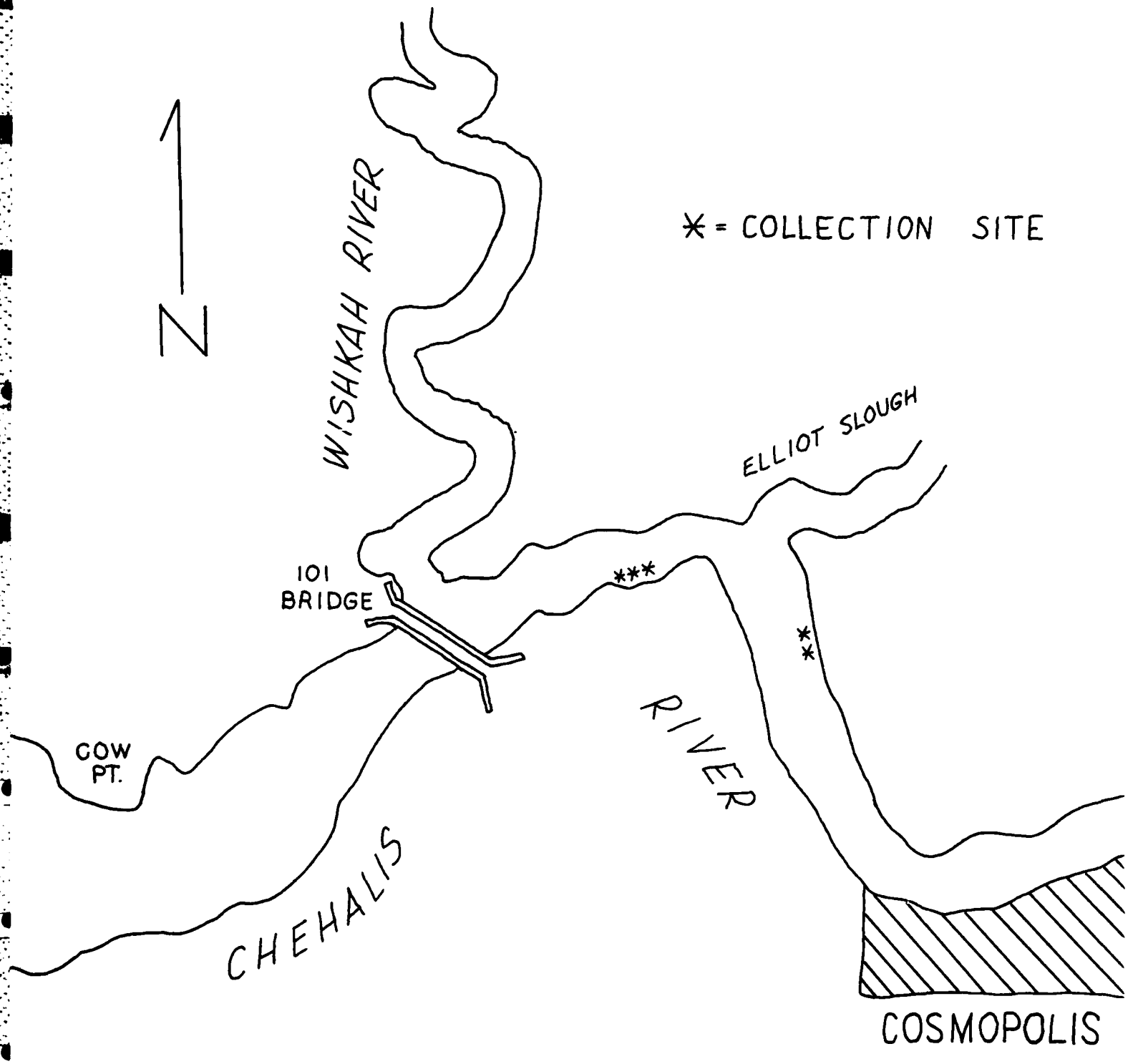
Sediments were collected from five upper estuary sites in Grays Harbor on 23 April 1982 (see figure 1). Collection was performed using a teflon coated 1 meter^2 Van Veen sampler. A total of 25 gallons of material was collected and placed in five 5-gallon sealed plastic containers and stored at 0° C within 4 hours after collection. Salinity measurements were taken .5 meters above the bottom at each collection site.

A subsample of material from each bucket was taken for immediate bulk sediment analysis of heavy metals. Samples for trace metals (except mercury) were digested using a HNO_3/HCl digestion procedure as described in Procedures for Handling and Chemical Analysis of Sediment and Water Samples, U.S. Environmental Protection Agency (EPA)/Corps of Engineers, May 1981, pp. 3-98. The remaining analyses (total solids, volatile solids, and mercury) were performed in accordance with procedures in Methods for Chemical Analysis of Water and Wastes, EPA, Office of Research and Development, Cincinnati, Ohio, March 1979. The reference used for this work was: "Interim Methods for the Sampling and Analysis of Priority Pollutants in Sediments and Fish Tissue" issued by EPA, Environmental Monitoring and Support Lab; Cincinnati, Ohio, 1980.

The fish used in this study were obtained from the Washington State Department of Fisheries' Simpson Hatchery on the Satsop River in Grays Harbor County, Washington. Approximately 550 coho salmon (O. kisutch) (25 pounds at 22 fish per pound) from brood year 1980 were delivered via fish hatchery truck to the U.S. Fish and Wildlife Service National Fisheries Research Station on Marrowstone Island, Washington, on 21 April 1982. The fish were acclimatized for 2 weeks and fed 1/8-inch Oregon Moist Pellets two times per day to satiation. The experiment did not commence until the true smolt status of the fish was verified. This was done by periodically subjecting a 10-fish subsample to a 24-hour seawater challenge test as described by Clarke and Blackburn, 1979. It was considered that no effect on smoltification had occurred when blood sodium levels under 170 millequivilents per liter (meq/l) were found in all fish which had undergone this test. On 4 May, five of these fish were selected at random and given the seawater challenge test for 24 hours. Blood sodium levels were measured on this group and a control group of five randomly selected fish which were kept in freshwater. The seawater challenge test and blood sodium measurements were repeated with five more fish on 11 May. On 16 May, 10 more of these fish were given the 24-hour seawater challenge test and blood sodium levels were measured and compared to the blood sodium levels of 10 more control fish.

On 18 May, the sediment exposure period was started. Two-hundred and forty fish of approximately equal length and weight were divided into groups of 20 and transferred to 12 experimental tanks, each holding approximately 80 liters of water. Waterflow rates into these tanks were

FIGURE 1


N
WISHKAH RIVER
* = COLLECTION SITE
ELLIOT SLOUGH
101
BRIDGE
***
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*
COW
PT.
CHEHALIS
RIVER
COSMOPOLIS
10000
5000
0
5000
10000
15000
FEET

initially set at 0.5 gallons per minute (gpm) or greater and were lowered to 0.25 gpm on the third day of contaminant exposure in an attempt to raise the turbidity levels in the tanks and prolong the usage of the available sediment.

Each one of the sealed 5-gallon buckets containing the frozen sediments was thawed as needed at room temperature for 36-48 hours prior to use. A measured amount of sediment was initially combined with 5 gallons of water in plastic buckets to form a concentrated sediment-water slurry. This mixture was poured through a 950 micron mesh size Nitex screen to reduce organic debris and then further diluted with water to a final sediment: water volumetric ratio of 1:166 in two 44-gallon plastic drums (slurry tanks) which were set up at a level above the experimental tanks. The plastic drums were connected by two 2-inch-diameter PVC pipes near their bases. This procedure was repeated as necessary (once every 4-6 hours) to keep the slurry tanks full throughout the 9-day exposure period. On day three of the contaminant exposure period, this ratio was decreased by half to 1:83 to increase the turbidity levels in the experimental tanks. The sediment in these slurry tanks was kept suspended through the use of a 5-gpm stainless steel centrifugal pump which drew the slurry out of a hole in the bottom of each slurry tank and discharged it back into the tank at the top via 1-1/2-inch PVC piping.

Mounted above the slurry tanks, nine diaphram-type chemical metering pumps each withdrew an average of 97 milliliters per minute (ml/min) of slurry from the tanks. Five pumps were originally set up, and Y connectors were put on four of these. However, flow regulation problems were caused by the Y connectors, so an additional four pumps were used. Each pump injected the slurry to an experimental tank via vinyl tubing (polyethylene tubing was tried and found to absorb too much of the pump injection pressure) and introduced the mixture into the tank next to the water inflow nozzles. Because the slurry tanks were above the level of the experimental tanks, back-pressure valves were installed at the sediment injection point at each tank to prevent siphoning of the slurry into the experimental tanks. No injection tubing was present in the control tanks. The chemical metering pump flow rates into each tank were adjusted to create turbidity levels between 20-200 nethphelometric turbidity units (NTU) in the tanks on each day of the experiment.

Turbidity levels, dissolved oxygen (DO) levels, temperature, and waterflow rates were checked daily. Photoperiod was adjusted weekly. The amount of light reaching the control tanks was reduced to the approximate level of the experimental tanks by placing brown paper over the clear plastic tank lids. Metering pump flow rates and waterflow rates were reset throughout the experiment to maintain the turbidity levels which occur during hopper dredging activities.

On 21 May 1982, the fourth day of the experiment, a random water sample was taken from one of the experimental tanks, which had a turbidity level of 180 NTU, for an elutriate analysis of heavy metals in the water of

the experimental tanks. This sample was filtered through a 0.45-micron membrane filter; then the filtrate was analyzed by atomic absorption. (Reference: Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio, March 1979.)

Four experimental groupings were set up, each consisting of three replicate tanks containing 20 fish per tank. The control group was held in noncontaminated freshwater for 9 days, then immediately subjected to a 24-hour seawater challenge test as described by Clarke and Blackburn, 1977. The second, or 0-hour recovery group, was exposed to Grays Harbor sediment for 9 days, then immediately subjected to the same 24-hour seawater challenge test in clean seawater as the control group. The third, or 5-day recovery group, was placed in freshwater which was contaminated with Grays Harbor sediment for 9 days, and were then placed into clean freshwater for a 5-day recovery period. At the end of this time, they were subjected to the 24-hour seawater challenge test as described above. The fourth group, or 10-day recovery group, was placed in freshwater which was contaminated with Grays Harbor sediment for 9 days and were then placed into clear freshwater for a 10-day recovery period. After this, they were subjected to the same 24-hour seawater challenge test as described above.

Feeding of the fish was conducted until the day before the experiment commenced. None of the 240 experimental fish were fed during the experiment since this species is a sight feeder and the high turbidity levels in the experimental tanks could affect the results by allowing differential feeding rates between the clear control tanks and the turbid experimental tanks.

After each group had undergone the seawater challenge test, the fish were anesthesized, five at a time, in 200 parts per million (p.p.m.) of MS-222. Each fish was weighed and measured and then its tail was removed at the caudal peduncle. Blood from the dorsal aorta was collected in 280-micron Natelson capillary tubes which had been treated with ammonium heparin. The tubes were sealed at one end and centrifuged in groups of six for 5 to 10 minutes until distinct separation of plasma and hematocrytes had occurred. The capillary tubes were then broken at the plasma-hematocryte interface and a portion of the tube containing the plasma was sealed at one end and immediately placed in a nonfrost-free freezer. The samples were kept frozen until analysis of blood sodium levels was performed on an atomic absorption flame spectrophotometer. Two standards were used for quality controls, and readings were checked every five samples to account for drift.

RESULTS

No fish mortalities occurred in any of the experimental tanks during the experiment. The results of the preliminary seawater challenge tests conducted on May 4, 11, and 16 can be seen in figure 2. The mean blood sodium levels decreased over time until the mean was 168 meq/1 with a standard error of 3.9 meq/1 on 16 May 1982. Since a level of 170 meq/1 was considered to be the upper limit of smolt classification for this experiment, the experiment commenced on 18 May 1982.

The mean turbidity level in the three control tanks was 0.89 NTU. The turbidity readings in the other tanks fluctuated randomly from 6 to 220 NTU's throughout the experiment. The mean for the nine tanks containing sediment throughout the entire experiment was 75 NTU. Turbidity levels by date and individual tank are presented in appendix A. No attempt was made to correlate turbidity levels with suspended solids concentrations.

Fish length and weight measurements can be seen in tables 1 and 2, respectively. The shortest mean length per tank was 123.1 millimeter (mm) in tank 48, and the longest mean length per tank was 129 mm in tank 54. The greatest standard error from a mean was 1.9 mm in tank 54. The mean fish weight varied from 15.9 grams in tank No. 47 to 20.2 grams in tank 51. The largest standard error was 0.8 grams in both tanks 53 and 54. Because the fish were not fed throughout the experiment, a comparison of length to weight was made for each tank to determine length or weight changes during the experiment. In table 3, a greater length to weight ratio can be seen in the 10-day recovery group compared to the other three groups. The fish in the 10-day recovery group were noted to be visibly emaciated in comparison to the three other groups.

FIGURE 2
SEAWATER CHALLENGE TEST BLOOD SODIUM LEVELS, MAY 1982

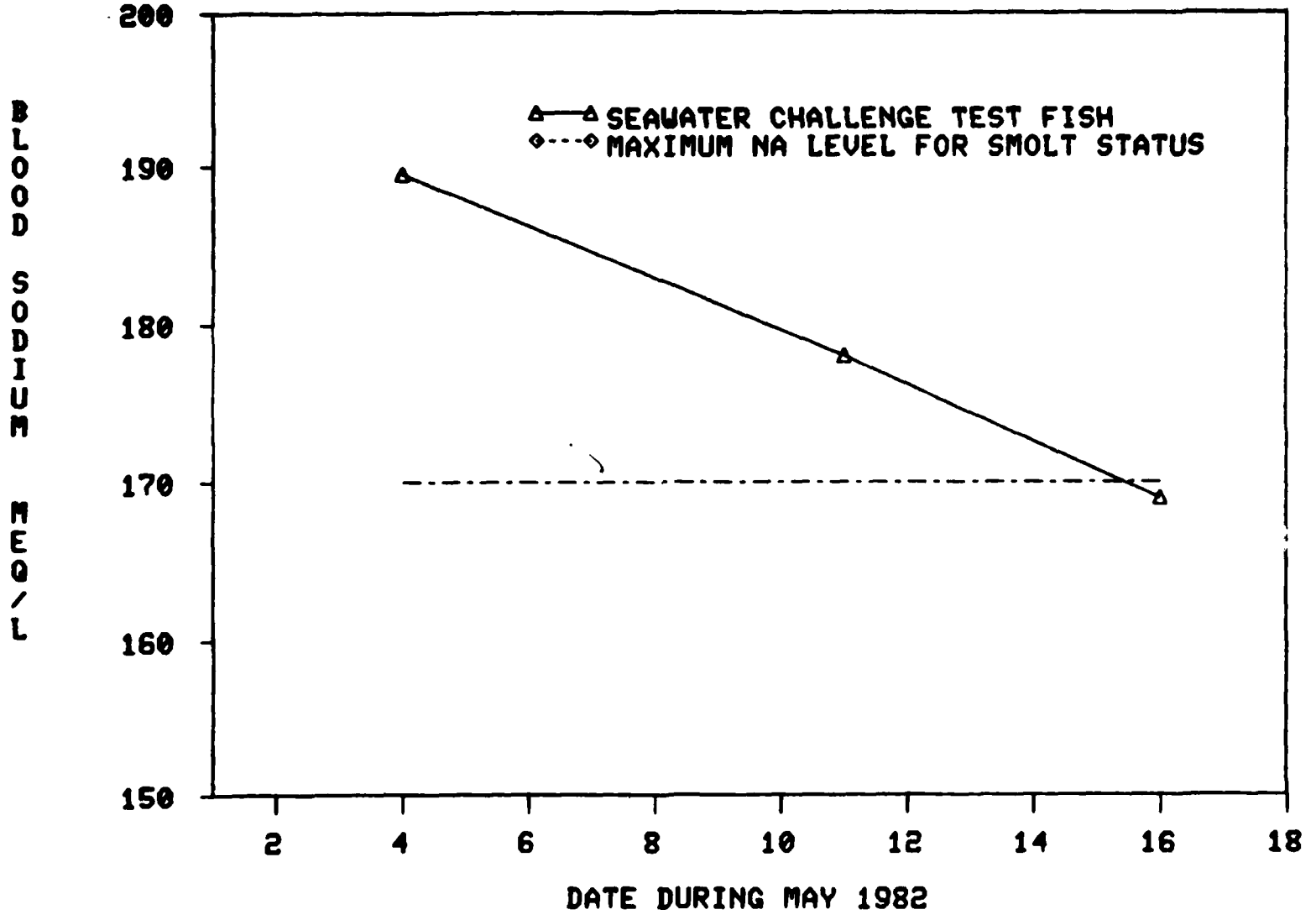

TABLE 1

FISH LENGTH (MM)

	Tank Number											
	47	48	49	50	51	52	53	54	55	56	57	58
Experimental* Group	(10)	(10)	(10)	(c)	(c)	(5)	(5)	(5)	(c)	(0)	(0)	(0)
1	124	122	125	136	119	116	127	130	117	126	121	128
2	132	133	135	130	120	117	117	137	121	130	130	128
3	120	119	117	130	121	124	123	135	124	119	131	127
4	119	123	137	128	131	133	118	136	123	125	136	117
5	126	135	124	123	122	124	129	129	125	118	121	129
6	119	124	127	131	130	140	133	124	119	114	118	117
7	113	125	119	117	119	138	125	122	135	113	126	125
8	135	127	112	130	133	129	124	136	121	128	133	126
9	121	119	131	121	132	126	111	146	123	128	133	134
10	120	114	132	124	124	121	117	131	120	138	116	126
11	118	121	125	120	135	142	120	125	133	126	131	124
12	122	122	125	132	128	124	130	125	129	136	133	125
13	130	124	129	123	120	134	131	126	117	139	129	123
14	135	119	130	124	138	127	135	111	130	124	125	128
15	125	120	133	126	132	126	135	136	132	132	115	124
16	116	125	139	125	135	133	128	114	126	125	113	130
17	122	122	125	126	140	123	121	130	144	130	124	125
18	120	120	122	116	115	127	128	123	126	119	116	134
19	119	126	118	127	131	139	131	136	125	115	124	137
20	129	122	137	126	122	129	139	127	121	120	113	117
Mean	123.3	123.1	127.1	125.8	127.4	128.6	126.1	129.0	125.6	125.3	124.4	126.2
S.D.	6.2	4.8	7.3	5.0	7.3	7.4	7.2	8.3	6.7	7.7	7.4	5.4
S.E.	1.4	1.1	1.6	1.1	1.6	1.7	1.6	1.9	1.5	1.7	1.7	1.2

*(10) = 10-day recovery period
(5) = 5-day recover period
(0) = 0-hour recovery period
(c) = control

TABLE 2

FISH WEIGHT (grams)

	Tank Number											
	47	48	49	50	51	52	53	54	55	56	57	58
Experimental* Group	(10)	(10)	(10)	(c)	(c)	(5)	(5)	(5)	(c)	(0)	(0)	(0)
1	16.3	14.5	16.9	23.9	17.2	14.2	18.7	20.9	12.8	18.9	17.0	19.9
2	19.9	19.9	23.8	19.2	16.9	14.3	14.3	24.8	16.5	20.0	21.9	18.4
3	13.4	15.4	14.0	19.5	17.3	16.6	16.0	21.4	18.0	16.9	19.4	19.6
4	14.1	15.0	22.0	19.6	22.9	22.0	15.0	22.8	15.2	18.1	25.0	15.0
5	18.2	21.0	16.1	17.9	17.1	17.3	18.3	17.9	17.3	14.7	17.1	21.1
6	14.5	16.0	16.7	20.0	21.9	24.2	22.0	17.4	15.8	13.3	15.9	15.2
7	11.5	18.4	15.9	15.6	16.5	24.0	15.2	16.5	23.9	13.0	20.0	20.1
8	21.5	17.0	15.3	20.8	23.4	18.8	18.0	21.1	16.8	18.9	23.0	19.2
9	15.1	14.5	18.3	17.5	22.9	19.5	11.8	28.0	16.4	18.8	23.0	22.5
10	14.1	13.0	20.0	19.5	18.1	14.8	14.2	20.0	16.4	24.8	15.0	19.1
11	13.0	14.8	14.6	15.2	23.1	26.0	16.0	18.2	21.7	17.9	22.9	18.0
12	16.0	16.5	16.8	22.2	19.8	17.7	19.8	18.1	21.0	22.7	21.0	17.0
13	19.3	13.8	17.1	17.2	16.0	21.0	20.0	18.0	14.7	24.2	20.2	17.2
14	21.1	14.2	18.5	18.3	25.9	17.6	24.0	12.5	20.8	17.0	18.9	21.4
15	17.4	15.3	21.0	18.9	21.4	17.2	24.0	22.4	20.4	20.8	15.0	18.0
16	13.0	18.1	22.7	17.3	23.1	21.0	17.9	13.5	18.9	17.0	13.5	20.0
17	13.0	15.0	17.0	19.0	25.0	15.8	15.5	19.5	27.9	19.2	17.5	17.9
18	13.9	14.4	17.0	14.9	15.0	19.4	18.9	17.0	19.7	15.7	17.0	21.1
19	14.9	17.9	14.9	18.0	22.0	24.0	20.1	22.0	18.7	14.0	19.0	23.0
20	17.8	15.0	22.0	18.2	19.0	18.0	25.0	19.0	16.6	16.5	14.0	16.0
Mean	15.9	16.0	18.0	18.6	20.2	19.2	18.2	20.0	18.5	18.1	18.8	19.0
S.D.	2.9	2.1	2.9	2.2	3.3	3.5	3.6	3.6	3.5	3.3	3.3	2.3
S.E.	0.6	0.5	0.6	0.5	0.7	0.8	0.8	0.8	0.8	0.7	0.7	0.5

*(10) = 10-day recovery period
(5) = 5-day recovery period
(0) = 0 hour recovery period
(c) = control

TABLE 3

LENGTH TO WEIGHT RATIO OF
EXPERIMENTAL FISH AFTER THE
SEAWATER CHALLENGE TEST
(mm:grams)

GROUP	TANK NUMBER	L:W RATIO
Control	50	6.76
	51	6.31
	55	6.79
0-Hour Recovery	56	6.92
	57	6.62
	58	6.64
5-Day Recovery	52	6.70
	53	6.93
	54	6.45
10-Day Recovery	47	7.75
	48	7.69
	49	7.06

Bulk sediment analysis data for heavy metals are presented in table 4. These results are reported on a dry weight basis, except total solids. These sediments were also analyzed for pesticides and polychlorinated biphenyls (PCB's). None were detected. The results of the elutriate chemical analysis performed on May 21 are contained in table 6.

Water temperatures, pH level, and DO levels in the freshwater and saltwater intake systems were monitored throughout the experiment. These values can be seen in appendix B. DO levels in the tanks were measured throughout the experiment also. The DO level was not below 7.0 milligram per liter in any tank measured during the experiment. Results of the DO measurements for the tanks can be seen in table 7.

Blood sodium levels for each tank as well as the four groups in the experiment can be seen in tables 8 and 9, respectively. The three control tanks had a mean blood Na level of 157 meq/l and a standard error of 2.3 meq/l. The three zero-hour recovery tanks had a mean of 145 meq/l and a standard error of 2.9 meq/l. The three 5-day recovery tanks had a mean of 168 meq/l and a standard error of 4.0 meq/l. The 10-day recovery tanks had a mean of 181 meq/l and a standard error of 2.2 meq/l. Statistically invalid data was removed and not used in the above calculations (Wedemeyer, 1982, personal communication).

TABLE 4

BULK SEDIMENT ANALYSIS FOR HEAVY METALS
IN GRAYS HARBOR SEDIMENT*

	Sample Bucket Number				
	# 1	# 2	# 3	# 4	# 5
Total Solids (%)	49.0	49.5	53.6	52.6	55.0
Volatile Solids (%)	11.2	8.2	9.2	8.0	6.0
Iron (%)	3.61	4.00	4.22	4.05 4.13	4.51
Copper (ug/g)	64.7	54.5	64.2	55.1 55.9	62.5
Zinc (ug/g)	97.8	98.4	107.	94.5 96.6	88.4
Lead (ug/g)	31.2	-	-	-	-
Nickel (ug/g)	30.8	-	-	-	-
Cadmium (ug/g)	1.04	-	-	-	-
Chromium (ug/g)	52.0	-	-	-	-
Mercury (ug/g)	0.10	-	-	-	-

*Results reported on a dry weight basis, except total solids, volatile solids, and iron.

- = not analyzed

Quality Control: Analysis performed on atomic absorption spectrophotometer using three standards, a blank, and an EPA reference standard. Standards were checked at least once in every 10 samples.

TABLE 5

DETECTION LIMITS FOR ANALYSIS OF SEDIMENTS
FOR PESTICIDES AND PCB'S (Ug/g)

Aldrin	0.003	Endrin Aldehyde	0.02
Dieldrin	0.006	Heptachlor	0.003
DDT	0.02	Heptachlor Epoxide	0.003
DDE	0.006	Alpha - BHC	0.003
DDD	0.02	Beta - BHC	0.003
Endosulfan I	0.006	Gamma - BHC	0.003
Endosulfan II	0.006	Delta - BHC	0.003
Endosulfan Sulfate	0.02	PCB's	0.16
Endrin	0.006		

TABLE 6

ELUTRIATE ANALYSIS OF GRAYS HARBOR SEDIMENTS

Metal Type	Quantity Measured (mg/l)	Current EPA Criteria (mg/l)
Copper	0.002	0.023
Zinc	0.012	0.058
Lead	0.001	0.025
Nickel	0.001	0.007
Cadmium	0.0001	0.005
Chromium	0.0010	0.018
Mercury	0.0002	0.0001

Quality Control: Analysis performed on atomic absorption spectrophotometer using three standards, a blank, and an EPA reference standard. Standards were checked at least once in every 10 samples.

TABLE 7

DISSOLVED OXYGEN LEVELS IN THE EXPERIMENTAL TANKS (mg/l)

	Tank Number											
	47	48	49	50	51	52	53	54	55	56	57	58
Experimental* Group	(10)	(10)	(10)	(c)	(c)	(5)	(5)	(5)	(c)	(0)	(0)	(0)
5/21	9.4	--	--	--	--	--	--	--	--	--	--	--
5/22	--	--	--	--	--	--	--	--	--	--	--	--
5/23	--	--	--	--	--	8.3	--	--	--	--	--	--
5/24	8.9	--	--	--	--	8.3	--	--	--	8.9	--	8.1
5/25	--	--	--	--	--	--	--	--	--	--	--	9.2
5/26												
12:30 p.m.	9.1	8.5	7.0	9.3	8.5	8.3	8.6	7.7	9.4	7.2	9.0	8.5
10 p.m.	--	--	7.8	--	--	--	--	8.7	--	7.0	--	--

-- = not sampled

*(10) = 10-day recovery period
(5) = 5-day recovery period
(0) = 0-hour recovery period
(C) = Control

TABLE 8

BLOOD SODIUM LEVELS BY TANK (meq/l)

	Tank Number											
	47	48	49	50	51	52	53	54	55	56	57	58
Experimental Group*	(10)	(10)	(10)	(c)	(c)	(5)	(5)	(5)	(c)	(0)	(0)	(0)
1	187.8	179.7	191.7	190.5	114.0	196.2	201.2	XXXX	157.2	157.1	121.2	151.5
2	208.6	218.8	189.5	175.4	178.3	148.0	189.7	117.7	161.8	154.3	128.3	158.3
3	205.0	156.9	176.8	162.1	135.5	192.9	XXXX	176.1	149.9	160.5	124.1	151.6
4	203.5	194.6	190.1	ND	144.6	ND	194.5	XXXX	161.6	ND	129.7	144.8
5	192.4	163.6	189.9	195.3	147.2	XXXX	227.7	178.0	151.3	138.2	133.2	137.4
6	173.9	192.5	161.2	82.0	147.6	136.6	XXXX	177.8	XXXX	169.1	119.4	139.8
7	191.1	166.5	163.5	164.7	160.8	203.7	218.9	165.4	138.4	147.7	157.4	147.9
8	181.4	192.1	158.7	182.3	158.5	171.2	145.2	168.4	154.2	175.2	172.1	142.1
9	190.6	156.4	164.5	151.8	144.5	182.5	204.5	182.7	159.3	171.6	123.2	145.6
10	186.5	164.9	198.0	180.2	147.1	127.4	194.8	155.8	144.4	172.1	112.9	151.5
11	194.6	196.3	196.6	151.2	144.9	ND	154.8	152.0	169.7	145.3	149.4	164.0
12	190.3	214.9	179.3	181.3	145.8	186.6	222.5	86.0	162.0	140.3	171.6	158.3
13	202.7	172.1	170.1	167.2	150.7	194.5	211.0	165.3	161.0	158.8	150.2	147.6
14	173.6	192.9	189.7	188.4	162.0	193.3	148.4	151.6	152.0	ND	148.3	ND
15	184.9	145.6	185.2	170.1	160.4	172.6	174.1	204.3	151.6	150.3	144.1	180.9
16	184.9	165.6	188.5	179.8	170.5	151.7	103.7	161.4	169.3	132.4	134.5	161.5
17	173.9	192.7	189.3	146.1	166.6	177.8	ND	158.7	171.7	127.7	144.7	139.0
18	180.0	161.1	154.1	170.8	161.0	169.3	XXXX	144.5	151.3	136.3	144.1	171.9
19	176.0	166.2	151.4	142.7	149.4	140.1	163.6	165.1	156.0	132.3	148.6	160.9
20	179.1	168.0	152.2	150.3	133.5	164.3	86.4	167.3	148.2	139.0	142.4	155.8
Mean	188.0	178.1	177.0	164.9	151.2	171.1	177.6	159.9	156.4	150.5	140.0	153.2
S.D.	10.8	20.1	15.9	25.4	14.4	23.3	41.4	25.7	8.7	15.1	16.4	11.5
S.E.	2.4	4.5	3.6	5.7	3.2	5.2	9.3	5.7	-	1.9	3.7	2.6

X = deletion (statistically invalid data) (Wedemeyer, 1982, personal communication.)
ND = no data
*(10) = 10-day recovery
(5) = 5-day recover
(0) = 0 hour recovery
(c) = control

TABLE 9

BLOOD SODIUM LEVELS
BY EXPERIMENTAL GROUP
(meq/1)

Group	Tank Nos.	Fish No.	Mean (meq/1)	S.D.	S.E.
Control	50, 51, 55	60	157.3	18.2	2.3
0-Hour Recovery	56, 57, 58	60	145.2	23.3	2.9
5-Day Recovery	52, 53, 54	60	168.0	31.0	4.0
10-Day Recovery	47, 48, 49	60	181.0	16.6	2.2

DISCUSSION

A great deal of variation in turbidity levels occurred in the experimental tanks throughout the contaminant exposure period. This variability correlates closely with naturally occurring variations in turbidity during hopper dredging operations. This variation was due to several factors. Sediment clogging of the chemical feed pumps and back-pressure valves, variations in particle sizes within the samples, the movement of the fish in the tanks, and siphoning of the sediment slurry from the slurry tanks to the experimental tanks all contributed to the fluctuations observed in the turbidity readings.

Although turbidity readings of about 200 NTU's were occasionally reached, the waterflow rates in the experimental tanks were not sufficient to keep the heavier material in the slurry suspended. This was evidenced by the effect of flow rate and slurry input rate changes on turbidity levels during the experiment. Despite doubling the slurry input rate and halving the water inflow rate on day three of the contaminant exposure period, significant increases in subsequent turbidity readings were not observed. Deposition of sediment up to 5-centimeters deep occurred in the experimental tanks, indicating that the water movement in the tanks was not great enough to keep all of the material suspended.

Slurry tanks should be constructed at a level below the experimental tanks to prevent siphoning. Also, with this adjustment, back-pressure values would not be needed in the system. These valves tended to clog with sediment before the chemical metering pumps did.

The true measure of the amount of material suspended in a given volume of water should be done by measurement of suspended solids concentrations. However, because turbidity readings, rather than this method of measurement, are widely used in conjunction with dredging operations, turbidity measurements were also used for this experiment.

Chemical analysis of both the sediments and elutriate from the Grays Harbor samples showed the presence of a variety of heavy metals. The concentrations found in the elutriate analysis were all below the levels which are considered to have an effect on juvenile salmon during parr-smolt transformation (Wedemeyer, et al., 1980). The question of the availability of these metals must also be considered; however, tests to examine this would not be justified unless an effect from heavy metal contamination was apparent. The effect of hydrogen-ion concentration (pH) on the availability of heavy metals should also be noted. Increases in pH levels tend to decrease the availability of heavy metals present. Analysis of STORET data for the Chehalis River near Grays Harbor shows an average pH of 7.2 for the last several decades. The pH at the freshwater inflow pipe at Marrowstone Island was approximately 7.8-7.9 during the experiment. This increase in pH would tend to make less heavy metals

available in their free ion state, and so this experiment would, therefore, tend to slightly mute any heavy metal effects occurring during dredging operations in Grays Harbor.

The intent of this experiment was to perform effect/no effect analysis of typically dredged Grays Harbor sediments on the osmoregulatory ability of smolting juvenile salmon migrating through the estuary. A blood sodium level of 170 meq/l or lower in exposed fish subjected to a 24-hour seawater challenge test was established as a range which demonstrated no effect of heavy metals on the osmoregulatory capacity of the smolts. A blood sodium level of 171 meq/l or greater was designated as an indication that osmoregulatory impairment was occurring (Wedemeyer, 1982, personal communication).

Previous work (Lorz, et al., 1978) has shown that if 5-day recovery periods before saltwater challenge are allowed, the effects of heavy metal exposure on seawater tolerance are reversed. However, in this experiment, the 0-hour recovery group and the 5-day recovery group were below the "effect" threshhold and are, therefore, not considered to have suffered any osmoregulatory impairment due to the exposure to the sediments. The smolts allowed to recover for 10 days showed signs of regulatory impairment, but these results are the reverse of what would be expected, based on previous work, and may be an artifact. There may be other factors affecting the ability of fish to osmoregulate, however.

The comparison of length to weight ratios provides a hypothesis to explain the cause of the higher blood sodium levels in the 10-day recovery group. These fish had gone without food for 20 days and were visibly emaciated. This form of stress may have affected the osmoregulatory capability of the fish. The question of whether this aspect of the experimental design affected the final blood sodium levels obtained cannot be answered without further investigation.

CONCLUSIONS

This experiment has closely replicated the field conditions found in Grays Harbor during hopper dredging operations in the inner harbor. Coho smolts were subjected to high levels of suspended sediments for 9 days. Twenty-four hours after introduction of these fish to seawater, the fish exposed to sediments showed no impairment of their osmoregulatory ability compared to the control fish. Smolts allowed to recover from the sediment exposure in freshwater for a 5-day period also showed no osmoregulatory impairment. The smolts allowed to recover for 10 days showed signs of regulatory impairment, but these results are the reverse of what would be expected based on previous work. They may be due to stress induced by lack of food or another aspect of experimental design.

Based on the above results, sediments released into the water column during dredging of the inner portion of Grays Harbor is not believed to impair the osmoregulatory capacity of smolting juvenile salmon migrating through the area.

Heavy metals were present in the sediment used for this experiment, although not generally exceeding EPA criteria. The availability of these metals in their most biologically harmful state (as free ions) cannot be determined with the detection tests performed. The purpose of the research was to assess the physiological impact of metals found in Grays Harbor sediments. As the sediment was shown not to impair the smolt's osmoregulatory ability, it was not necessary to establish their availability.

APPENDIX A

DAILY TURBIDITY LEVELS (NTU)

	Tank Number and Group											
	47	48	49	50	51	52	53	54	55	56	57	58
Experimental Group*	(10)	(10)	(10)	(c)	(c)	(5)	(5)	(5)	(c)	(0)	(0)	(0)
5/19	30	30	28	1.4	1.8	26	18	18	1.2	76	27	54
5/20	22	92	6	0.8	0.6	51	61	22	0.7	54	42	20
5/21	150	180	72	-	-	90	120	40	-	90	86	50
5/21	140	60	76	-	-	90	100	44	-	82	80	62
5/22	-	-	-	-	-	66	44	30	-	72	-	160
5/23	82	125	92	0.7	0.7	100	64	40	0.9	105	65	55
5/24	180	55	40	0.6	0.6	74	57	-	1.3	79	54	195
5/25	38	7.0	56	0.9	0.7	71	52	29	1.0	74	67	220
5/26	145	200	70	1.1	0.5	66	85	22	0.9	76	56	203
5/27	135	195	65	1.0	0.6	25	52	55	0.7	140	22	36
Mean	102.4	104.9	56.1	0.9	0.8	65.9	65.3	33.3	1.0	84.8	55.4	105.5
S.D.	60.1	73.4	26.9	0.3	0.5	25.6	29.3	12.2	0.2	23.4	22.0	78.8
Standard Error	20	24.5	9.0	0.1	0.2	8.1	9.3	4.1	0.1	7.4	7.3	24.9

- = not measured
*(10) = 10-day recovery
(5) = 5-day recovery
(0) = 0-hour recovery
(c) = control

APPENDIX A (con.)

TURBIDITY LEVELS
BY EXPERIMENTAL GROUPS
(NTU)

	GROUP			
	Control	0-Hour Recovery	5-Day Recovery	10-Day Recovery
Mean for 5/19-5/27	0.9	82.8	55.6	86.8
Standard Deviation	0.3	52.3	27.6	60.5
Standard Error	0.04	6.8	3.6	7.8

APPENDIX A (con.)

DAILY TURBIDITY LEVELS FOR
NONCONTROL TANKS (NTU)

Date	Mean Turbidity Level In Noncontrol Tanks (NTU)	S.D.	S.E.
5/19	34.1	18.9	6.3
5/20	41.1	26.6	8.9
5/21	84.3	42.7	14.2
5/22	74.2	51.0	17.0
5/23	80.9	27.0	12.1
5/24	91.8	60.0	21.2
5/25	68.2	61.0	20.3
5/26	102.6	65.0	21.7
5/27	80.5	61.0	20.3

APPENDIX B

WATER TEMPERATURE, pH, AND DISSOLVED OYYGEN LEVELS IN FRESHWATER AND SALTWATER INTAKE LINES

FRESHWATER INTAKE LINES

Date	Temp H_2o (^oc)	pH	D.O. (mg/l)
5/17	11.0	7.88	10.52
5/19	11.0	7.85	10.31
5/21	11.3	7.78	9.88
5/24	11.5	7.72	8.62
5/26	11.7	7.88	9.70
5/28	12.0	7.85	9.10
6/2	12.8	7.79	8.95
6/4	12.8	7.78	4.60
6/7	12.6	7.90	5.72

SALTWATER INTAKE LINE

Date	Temp H_2O (^oC)	pH	D.O. (mg/l)	Salinity ($^o/oo$)
5/26	10.0	8.00	8.37	27.2
5/28	10.2	7.98	8.13	27.0
6/2	11.0	8.02	9.00	26.1
6/7	11.0	7.99	8.52	26.0

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